Conceptual Model Development and Validation

RPG Special Topic

11/30/00

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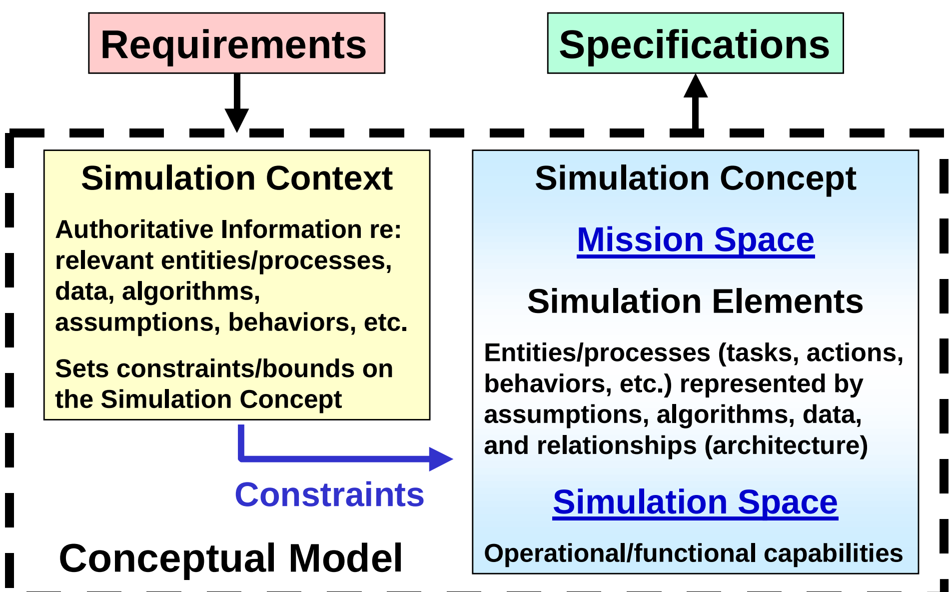
This document corresponds to the web version of the VV&A RPG Special Topic of the same name and date. It has been modified to make it suitable for printing.

Introduction

After basic definitions and introductory comments, the paper addresses simulation conceptual model development, conceptual model documentation, and conceptual model validation.

Simulation Conceptual Model

A simulation conceptual model is a Developer's way of translating the requirements into a detailed design framework, from which the software that will make up the simulation can be built. A simulation conceptual model is the collection of information which describes a Developer's concept about the simulation and its pieces. That information consists of assumptions, algorithms, relationships (i.e., architecture), and data. Taken together, these items describe how the Developer understands what is to be represented by the simulation (e.g., entities, actions, tasks, processes, interactions) and how that representation will satisfy the requirements to which the simulation responds [see the special topic Requirements]. A simulation conceptual model can be a primary mechanism for clear communication among simulation design and implementation personnel (e.g., systems analysts, system engineers, software designers, code developers, testers), Users, subject matter experts (SMEs) involved in simulation reviews, and verification, validation, and accreditation (VV&A) personnel. A simulation conceptual model, shown in the figure below, addresses the simulation context, simulation elements, and the simulation concept.



Conceptual Model Components

Simulation Context

The **simulation context** provides authoritative information about the domain that the simulation is to address. Often this part of the conceptual model is merely a collection of pointers and references to sources that define behaviors and processes for things that will be represented within the simulation.

> Example:
>
> This part of the conceptual model may identify such things as sources for the algorithms used for calculating radar signal propagation, operational modes possible with particular pieces of equipment, organizational structure and possible information-flow paths of a military unit, etc.

Special care must be used when algorithms are taken from more than one source to ensure that those sources do not employ contradictory assumptions or factors (such as different models for the shape of the earth, the characteristics of the environment, etc.). Information contained in the simulation context establishes boundaries on how the Developer can properly build the simulation.

Simulation Concept

The **simulation concept** describes the Developer's concept for the entire simulation application (i.e., all the federates and other pieces in a distributed simulation; everything that comprises the simulation) and explains how the Developer expects to build a simulation that can fully satisfy user-defined requirements. The simulation context just discussed establishes constraints and boundary conditions for simulation concept.

> Example:
>
> If the simulation is concerned with realistic representation of missiles or aircraft in flight, then the laws of physics and the principles of aerodynamics are part of the simulation context and require (constrain) the simulation concept to accommodate conservation of momentum, etc. Unrealistic, cartoon representations of missiles or aircraft in flight would not necessarily be so constrained.

The simulation concept has two primary aspects: mission space is concerned with representation, and simulation space is concerned with simulation control. The mission space includes simulation elements (i.e., the things represented in the simulation). The simulation concept, then, is the total of all simulation elements, specifies how they interact with one another, and includes all additional information needed to explain how the simulation will satisfy its objectives. A primary function of the simulation concept is to serve as the mechanism by which simulation requirements are transformed into detailed simulation specifications (and associated simulation design) that fully satisfy the requirements. The simulation concept has to address both the representational aspects of the simulation (i.e., its mission space) and the functional aspects of the simulation (i.e., its simulation space) such as its hardware and software operating systems. We reserve extended discussion of simulation space to the end of this document.

Simulation Element

A **simulation element** consists of the information describing concepts for an entity, as well as for a composite or collection of entities or processes that are represented within a simulation. Simulation elements include assumptions, algorithms, data, relationships (especially interactions with other things within the simulation), etc., which identify and describe that item's possible states, tasks, events, behavior/performance, parameters and attributes, etc.

A simulation element can address a complete system (e.g., a missile or radar), a subsystem (e.g., the antenna of a radar), an element within a subsystem (e.g., a circuit within the transmitter of a radar), or even a fundamental item of physics (e.g., an atom). It can also address composites of systems (e.g., a ship or aircraft with its collection of sensors and weapons). A person, part of a person (e.g., a hand), or a group of people can also be a simulation element. A simulation element can address a process such as environmental effects on sensor performance. In a distributed simulation (i.e., a federation), each of the simulations (federates) would be a simulation element in this terminology.

Federation Conceptual Model (FCM)

The second activity in federation development, the development of the federation conceptual model, as presented in the High Level Architecture (HLA) Federation Development and Execution Process (FEDEP), results in three key products: federation requirements, federation conceptual model (FCM), and federation scenario. It is helpful to explain the relationship of these to the simulation context, simulation element, and simulation concept of the conceptual model. It is also useful to note that the FEDEP process, illustrated in the FEDEP process diagram, uses "federation objectives" in the way that "requirements" are normally used for simulation development; and "federation requirements" more like "specifications" in normal simulation development (i.e., something with enough detail to drive design and implementation). Failure to appreciate the connotations attached to these terms in the FEDEP process model can lead to confusion when similar terms (such as requirements) are use with slightly different connotations.

Federation requirements and the federation scenario are roughly equivalent to the simulation context in the way that term is used here. They establish the constraints for the specific application of the distributed simulation (what it is intended to do).

Terminology Correspondences	
M&S	**FEDEP**
Requirements	Federation objectives
Specifications	Federation requirements
Simulation concept	FCM
Simulation Context	Federation requirements federation scenario
Simulation Element	Federates

The FCM, which addresses what federates (simulations) will be used together in the federation, is equivalent to the simulation concept. Federates correspond somewhat to the simulation elements in the simulation concept. Fuller discussion of the FEDEP, its elements, and tools developed to facilitate HLA federation development and execution may be found at the DMSO HLA website.

Conceptual Model Function

The conceptual model is the means by which simulation requirements can be transformed into simulation specifications that then drive simulation design. A simulation conceptual model may precede many simulation design and implementation decisions, allowing the conceptual model to be largely independent of design (and implementation). This generally is a more flexible and desirable approach. However, in some situations, a simulation conceptual model will include design considerations, especially when parts of the simulation are reused from a previous simulation or when it is decided a priori to use a particular hardware or software environment for the simulation. Sometimes, the simulation conceptual model will even be expressed in the descriptive environment chosen for simulation development, such as the Unified Modeling Language (UML) associated with object-oriented developments or one of the formal method paradigms employed when assured correctness is required (as in safety-critical applications).

Some simulation developments fail to create distinct documentation for the simulation conceptual model. This invariably leads to difficulties later. When one has to use a legacy simulation for which conceptual model documentation is not available or is grossly inadequate, construction of the presumed conceptual model can significantly increase the cost of validation endeavors. Adroit Users and Developers insist upon distinct and current documentation of the simulation conceptual model.

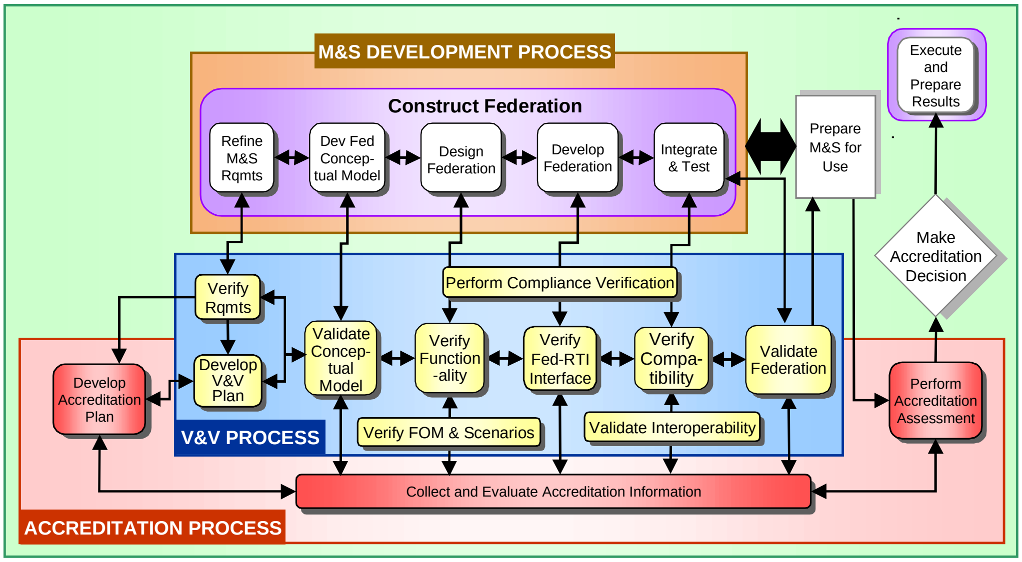
A specific area of unavoidable ambiguity exists in discussing the simulation conceptual model. The simulation conceptual model is the generic idea for the simulation to support its full spectrum of applications. For data-driven simulations, it is possible either to construct the simulation with data embedded or to construct the simulation so that it draws data from the inputs for a particular application of the simulation. Different conceptual models would be used for each approach, as illustrated in the following example.

> Example:
>
> If one wants to explore potential consequences of changing the power of a radar represented in the simulation, that parameter could be set by an input value and a single simulation conceptual model would suffice for multiple applications, each of which varied the radar's power. The radar's power could also be made an embedded parameter of the simulation element describing the radar, in which case a separate conceptual model would be required for each version of the radar considered (i.e., those with greater or lesser power).

Conceptual Model Development

Development Paradigms

Simulation development involves the definition of simulation objectives (i.e., establishing requirements); development of the simulation conceptual model, which allows specifications to be articulated so they can provide adequate detail to support design and implementation; design and development (implementation) of the simulation; testing and integration of the simulation; followed by use of the simulation. The specific process by which all this is accomplished depends on a number of factors including the size and complexity of the program, availability of resources, and time. A number of development paradigms have evolved, ranging from the basic waterfall development, where steps are taken sequentially, to the rapid prototype, where incremental releases are involved. (See the special topic on development paradigms for additional information.) The VV&A and Federation Construction process diagram shown below is a basic paradigm that can be applied to distributed simulation.



VV&A and Federation Construction

9/26/00

Development Process

Simulation requirements and conceptual model development are a classic "chicken-egg" pair. They each stimulate and derive from the other. Thus, conceptual model development can begin prior to completion of simulation requirements, or development of the simulation conceptual model may not begin until simulation objectives have been established and stated in a set of requirements for the simulation.

Four basic steps are involved in developing a simulation conceptual model. They can be repeated many times.

Conceptual Model Development Process
Collect authoritative information that establishes the simulation context.
Decompose the mission space into simulation elements (this defines the level of granularity, the aggregation/de-aggregation of the simulation).
Employ abstraction for description of simulation elements (this determines representational accuracy and such).
Address relationships among simulation elements.

Step 1: Collect Authoritative Information.

Authoritative information is needed about the intended application domain that will constitute the simulation context. Collection of such authoritative information may involve the use of knowledge engineering techniques and processes of knowledge acquisition/elicitation/representation developed for articulation of rules for expert systems [Knowledge Engineering website]; methods developed for problem formulation in operations research and systems analysis [Miser & Quade, 1996]; or, other formalisms employed in creating authoritative descriptions of entities, processes, and situations. However, development of the simulation concept and collection of authoritative information for the simulation context are likely to occur iteratively as the entities and processes to be represented become more clearly defined, regardless of which approach is taken to collecting the authoritative information.

> Example:
>
> The DMSO is developing authoritative descriptions of various military activities as part of the Functional Description of the Mission Space (FDMS)[1]. The FDMS authoritative descriptions ("the first abstraction of the real world . . . an authoritative knowledge source for simulation development . . . capturing the basic information about important entities involved in any mission and their key actions and interactions" [Lewis & Coe, 1997]) can help to ensure commonality of perspective among various Defense simulations and should facilitate reuse of simulation components which will make both new simulation development and existing simulation modification more economical. Authoritative descriptions of military activities can be used for part of the simulation context when appropriate for a simulation's intended application, just as can the laws of physics and similar principles be used for other parts of the simulation context.

The formal, documented simulation context is unlikely to address everything needed to fully describe the domain that a simulation is to address. The FDMS endeavors described by Sheehan et al [1998] emphasize a disciplined procedure by which the Developer is systematically informed about the real world and about a set of information standards that simulation SMEs employ to communicate with and obtain feedback from military operations SMEs. The keys to removing potential ambiguity between the ideas of the warfighting SMEs and the simulation development SMEs are

- common semantics and syntax
- common format database management system (DBMS)
- data interchange formats (DIF)

While significant progress has been made in developing a FDMS toolset to provide the keys noted above, their implementation to date, such as reported by Johnson [1998], has shown that information beyond what is likely to be obtained in the first level abstraction (i.e., FDMS) may be required for simulation conceptual models, and SMEs may be "called upon to fill in details needed by Developers" that are "not provided in doctrinal and/or authoritative sources." Clearly, the more completely and clearly stated

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[1] Designated as the Conceptual Model of the Mission Space (CMMS) in DoD 5000.59-P, *DoD M&S Master Plan*. The term CMMS is in the process of officially being changed to FDMS.

a simulation context is, the easier it will be to understand where and how one simulation may differ from another in its assumptions about the domain involved. This becomes very important when questions of compatibility among simulations (federates) considered for a distributed simulation implementation (federation) are addressed.

Sometimes it becomes obvious that additional information about the simulation context is needed if the simulation is to achieve its objectives (e.g., available information is inadequate, not just that it is not part of the authoritative description of the application domain). This often occurs for simulations used to support new system designs, and test programs may be established to generate such information. Sometimes the missing information consists only of parameter information (e.g., the strength of a material or the signal level at which specified levels of distortion occur); other times, the missing information concerns the theory (or algorithms) used to describe entity behavior or performance.

> Example:
>
> How does the volume of a material change with temperature? Where does it change from solid to liquid to gas?

When significant information about critical aspects of a simulation is unknown or uncertain, development of the simulation conceptual model can be more difficult because the set of algorithms and data will be incomplete. The text by Roache [1998] provides an excellent discussion of concerns about experimental (test) data, its limitations and uncertainties, its generation, and its relationship to simulation V&V. Sometimes inadequate attention is given to potential problems with the quality (correctness and comprehensiveness) of information upon which the simulation conceptual model is based.

Step 2: Decompose the Mission Space

The simulation elements are determined by the decomposition of the mission space. Six basic principles guide this decomposition:

Principles for Mission Space Decomposition
There should be a specific simulation element (parameter, entity, etc.) for every item (parameter, entity, etc.) specified for representation in the simulation by simulation requirements.
There should be a specific simulation element (parameter, entity, etc.) for every item (entity, task, parameter, state, etc.) of potential assessment interest related to the purpose of the simulation.
There should be "real world" counterparts (objects, parameters for which data exist or could exist, etc.) for every simulation element as far as possible. The potential impact of data, and metadata structures, on simulation elements and the simulation conceptual model should not be underestimated.
Wherever possible, the simulation elements should correspond to "standard" and widely accepted decomposition paradigms to facilitate acceptance of the conceptual model and effective interaction with other simulation endeavors

(including reuse of algorithms and other simulation components).
Simulation elements required for computational considerations (e.g., an approximation used as a surrogate for a more desirable parameter that is not computationally viable) that fail to meet any of the previously stated criteria should be used only when absolutely essential.
There should not be extraneous simulation elements. Elements neither directly related to specific items in the simulation requirements nor directly implied by potential assessment issues and elements without a specific counterpart in the real world or in standard decomposition paradigms should not be included in the simulation conceptual model. Every extraneous simulation element is an unnecessary source of potential simulation problems.

To accomplish its objectives, the entities and processes that must be represented in the simulation should be identified by the six decomposition principles just listed. This enumeration process is fundamental in conceptual model development. Here basic decisions are made about the level of detail and aggregation that is appropriate to support simulation requirements. These decisions determine whether a system (e.g., a radar) will be represented as a single entity, as a composite of subsystem entities (e.g., antenna, transmitter, receiver, etc.), or as a composite of composites of ever smaller entities (to whatever level of detail is needed for the purpose of the simulation). This is where decisions are made about the level of representation of human decisions and actions.

Example:

In the movement of a platform (tank, aircraft, ship, etc.), are the decisions and responses of all the people involved (the crew) represented implicitly as a single aspect of the movement control process, or is each person involved represented explicitly (as in a tank simulator with a position for every member of the tank crew)?

Step 3: Describe Simulation Elements

A simulation element is needed for each entity or process (or composites of such) identified in step 2. The basic representational abstraction issue is how to describe that simulation element - how to capture relevant characteristics. Here, decisions are made initially about the level of accuracy, precision, resolution, etc. needed in the representation of the entity or process. Simulation fidelity is a function of both the scope of representation in a simulation (i.e., the entities and processes identified in step two) and the quality of entity and process representation in terms of accuracy, precision, etc. [See the special topic Fidelity for additional information.] Simulation elements determine functional and behavioral capabilities of the simulation.

Knowledge engineering forms the heart of representational abstraction for a simulation conceptual model. Theoretical approaches to knowledge engineering typically break it into three phases: knowledge acquisition, knowledge elicitation, and knowledge representation. Such theoretical approaches usually identify three knowledge structures, each with different acquisition, elicitation, and representation techniques:

- declarative knowledge (why things work the way they do)
- procedural knowledge (how to perform a task)
- strategic knowledge (the basis for problem solving)

Unfortunately, these theoretical approaches do not yet allow abstraction to be performed as a scientific method; abstraction remains an art. [Knowledge Engineering website]

A review of recent articles in such publications as the *Journal of Data and Knowledge Engineering* [Elsevier Science website] reveals that contemporary researchers in this arena often develop a "new" descriptive language (or dialect) or formalism for the problem at hand because current techniques do not yet have broad, general application capabilities.

As one develops a simulation conceptual model and evaluates it by the criteria of clarity, completeness, consistency, and correctness, it is important to record how one assesses the model and then to note why it changes in response to the evaluation, and how criteria for a quality conceptual model are met more fully. Otherwise, the rationale for some changes (and their benefits) may be lost as time passes, and lessons learned from the conceptual model development will not be readily available for use in subsequent developments.

The bottom line is simple: Consistent and comprehensive use of any formalism in conceptual model development is better than the common, ad hoc, unstructured approach frequently used.

Step 4: Identify Relationships

The final step is to identify all of the relationships among simulation elements. This step should ensure that the constraints and boundary conditions imposed by the simulation context, as well as the operational and functional capabilities expressed in simulation requirements, are accommodated, and it should ensure that the simulation concept is fully articulated.

Development Considerations

These four basic steps may be iterated a number of times throughout the development process as requirements change or modifications are made to design, data, or code.

Abstracting Reality

A simulation conceptual model should be developed within the larger context of simulation theory. The approach to abstracting reality into simulation terms is a key aspect of simulation theory. Without a coherent approach to such abstraction of reality, the different parts of the simulation are likely to be incompatible in some way with one another. A number of approaches to simulation theory are available. These include the approaches espoused by proponents of Application Domain Modeling (ADM) such as Hone and Moulding [1999] and by proponents of the Discrete Event System Simulation (DEVS) methodology developed by Zeigler et al [1999]. Others prefer approaches to abstraction of reality for simulation based upon Casti's ideas [Casti, 1989]. Many within NASA stress use of formal methods where appropriate. The larger context of simulation theory can help to ensure that simulation conceptual model development has coherence and can be related more directly to all aspects of simulation development.

Problem Identification

Development of a simulation conceptual model will often reveal problems with requirements for the simulation, especially if simulation requirements were not rigorously validated before the start of conceptual model development. As the simulation conceptual model is developed to fully satisfy simulation requirements, inconsistencies among requirements and lack of balance among the requirements (e.g., some very lax and others very stringent in the same general area) may become apparent. Development of the simulation conceptual model may also reveal serious holes in the requirements, areas where the Developer is left to his own initiative about what the simulation should be able to do. A well-structured simulation development program will encourage (if not insist upon) early formal and rigorous validation of simulation requirements and will ensure that requirement deficiencies uncovered during conceptual model development are corrected with appropriate modification to the simulation requirements.

Conceptual Model Documentation

Format Alternatives

The varied nature of simulation conceptual models makes it impossible to provide a simple cookbook approach for their description that will work for all. Flexibility must be allowed to accommodate the variety of simulation conceptual models. The structure presented later in this section is intended as a guide to ensure that all needed information is available in the conceptual model description. The objective of the descriptive format for a simulation conceptual model is a coherent set of information that **fully** and **correctly** describes the conceptual model so that its capabilities, limitations, and characteristics can be readily understood by simulation development personnel, by VV&A personnel, and by SMEs involved in simulation assessments. The goal is to provide adequate information for a scientifically compelling understanding of the simulation conceptual model when possible. Simulation conceptual model documentation should provide adequate information for logical, complete, and factual assessment of the simulation conceptual model.

The following sections discuss four basic formats for describing simulation conceptual models which are listed:

Conceptual Model Description Formats
• Ad Hoc Method
• Design Accommodation
• Development Paradigm
• Scientific Paper Approach

The description of a given simulation conceptual model may employ more than one of these approaches.

> Example:
>
> The conceptual model description may employ design accommodation, using Yourdon Structured Analysis to facilitate precise specifications and the Unified Modeling Language (UML) to reduce ambiguity for code developers and to facilitate use of automated consistency and traceability checks. This part may then be coupled with the scientific paper approach to ensure comprehensive description of assumptions, algorithm sources, and other critical factors that are important elements of the simulation conceptual model and which are needed to fully support conceptual model validation.

This kind of approach to simulation conceptual model documentation also will facilitate any future modifications to the simulation.

Ad Hoc Method

The ad hoc method is the most common method for describing simulation conceptual models. This label is used because ad hoc means for the particular end use or case at hand, without consideration of wider applications. No formal attention normally is given to consistency (or completeness) of conceptual model descriptions using the ad hoc method. The conceptual models built for many legacy simulations employed this method, and thus it may be difficult to find even partial documentation of the simulation conceptual model.

Those who must use a legacy model (or perform conceptual validation of a legacy model) that does not have adequate documentation of its conceptual model must develop some level of understanding of the conceptual model upon which the simulation was built. Sometimes this reengineered conceptual model is developed by analysis of the simulation's code coupled with the documentation that may exist. Sometimes those who developed and those who used the simulation are interviewed to pull out of their minds insights about the simulation's conceptual model. Sometimes resources required to reengineer a conceptual model for a simulation are not available, and the simulation must be treated as a "black box" whose results must be suspect except where they agree with reliable information from other sources. This limits the level of confidence (i.e., the credibility) that can be placed in simulation results for any other conditions.

Design Accommodation

In this approach, the Developer employs descriptive formats that have been selected to support simulation design as the method to describe the conceptual model. However, there may be no standard method for capturing assumptions and limitations inherent in the conceptual model. Also, parts of the conceptual model for a particular system (e.g., a sensor) may be scattered throughout the simulation design. This can make it quite difficult for a conceptual validation review SME to have confidence that materials gleaned from the mass of design description information describe all aspects of the conceptual model being reviewed. Some design accommodation descriptive formats do not easily capture all critical elements of a conceptual model, such as temporal dependencies and relationships among simulation elements.

> Example:
>
> UML is being widely used in simulation development, and some believe that it can be used to adequately describe the simulation conceptual model as well. Unfortunately, UML documentation usually fails to provide a consistent and rigorous way to capture assumptions about simulation elements or pedigrees for algorithms used in the simulation, which can impede validation reviews of conceptual models. In addition, the documentation about a particular simulation element may not exist as a distinct entity; parts may occur in many different locations. Thus, as valuable as UML is for simulation development, its paradigm is unlikely to produce a thoroughly documented simulation conceptual model that can be readily used and understood by others.

Conceptual Model Development Paradigm

A third descriptive format for conceptual models is the DoD FDMS paradigm. FDMS approaches to date have emphasized database management system structures. As described by Sheehan et al [1998], these approaches have focused upon information sets about simulation entities, actions, tasks, and interactions (EATI). A set of tools has been developed to help transform information from military (warfighter and other operational) specialists and SMEs about an application domain into reusable EATI items of information [Johnson, 1998]. The infrastructure that DMSO has established to support FDMS provides a valuable resource for managing information parsed in this way and may also be helpful for managing other kinds of descriptions of conceptual models.

Scientific Paper Approach

This method tends to be more complete in its identification of assumptions, more explicit in its statement of algorithms in accord with standard mathematical and technical conventions, and more rigorous in its specifications of limitations associated with the simulation conceptual model. Because this method of conceptual model description is the most amenable to robust support for conceptual model validation reviews (and the most accommodating to simulation reuse and modification), it is the recommended approach for documentation of simulation conceptual models.

A simulation design that only partially satisfies simulation requirements is a common problem. Use of the suggested descriptive format is an important step in reducing the risk that a simulation design will not fully satisfy its requirements and the risk that simulation problems will lead to costly losses. The cost of software problems can be very high, as illustrated by the half-billion dollar-plus loss from the Ariane 5 disaster [Doyle, 1997] and by the billion dollar-plus loss from the April 1999 Titan IV failure [Wall, 1999]. As more weapons system design decisions are based predominately on simulations and as more decision aids are based on simulations, opportunities for similar costly losses will exist whenever simulation V&V is inadequate. Quality of the simulation conceptual model documentation has a significant impact on simulation validation endeavors [Pace, 1998].

The following sections describe a scientific paper approach for simulation conceptual models that is appropriate for new simulation developments, for major simulation modifications, and for reengineered conceptual models of legacy simulations. The nine sections discussed can be applied to any component of a simulation conceptual model (i.e., simulation context, simulation concept, individual simulation elements) or to all of them. This list of items is functionally equivalent to the 10 items in the generic content guidelines from IEEE/EIA 12207 for describing a planned or actual function, design, performance or process [IEEE, 1995; Sorensen, 1999]:

Generic Content Guidelines	
Date of issue and status	Scope
Issuing organization	References
Context	Notation for description
Body	Summary
Glossary	Change history

Using the scientific paper approach to describe simulation elements is particularly important because a major part of most conceptual model validation reviews is assessment of simulation element representation.

Conceptual Model Part Identification

The identification section should be unique and easy to understand. An abbreviated version may also be used to facilitate indexing. In both cases, the identification should include a date indicating the completion or release of the conceptual model (or part of a model) involved.

Example:
The simulation element in the conceptual model representing a radar of Type X

> might be identified as: "SimY Radar Xv3 (05/05/99)." That identifier would be 5 May 1999 version 3 of the representation of radar Type X in Simulation Y.

Such precision in labeling a conceptual model description becomes very important in establishing the appropriateness of what is being assessed in a conceptual validation review.

Principal Points of Contact (POCs) for the Conceptual Model

This section should identify the specific individual(s) (e.g., developers, reviewers, SMEs) associated with the conceptual model, or part of it, so everyone involved can know whom to contact for clarification, additional information, or discussion. Contact information to include is shown in the table below:

Contact Information
Name
Telephone number
Fax number
E-mail address
Specific area of responsibility

Conceptual Model Part Requirements/Purpose

This section should be a brief but specific and detailed description of what the conceptual model (or the particular part of it being described) is supposed to do. This description should establish the specific perspective to be employed when that representation is reviewed and should include a mapping of specific simulation requirements to simulation elements.

One approach is to use the FDMS data structure in the description of a conceptual model to ensure a direct linkage between the conceptual model and items in the FDMS repository. However, when multiple levels of resolution are involved (as in the federation of a distributed simulation), it may be appropriate to use a different data structure [Davis & Bigelow, 1998]. Community standards for how to deal with this issue do not yet exist.

Conceptual Model Part Overview

This section provides a general description of the simulation and explains how the conceptual model (or the part being documented) relates to the larger application domain. In particular, interactions and interfaces of the simulation elements within the application domain should be specified. If distinct documentation of the conceptual model is not provided, the reviewer will need to pore over the complete collection of simulation documentation (software design documentation [SDD], UML diagrams, etc.) to collect the material describing the conceptual model. This can involve extensive time and introduces significant potential for error. Material can be missed, and extraneous items can be included. Both will make evaluation of the conceptual model more difficult and increase the possibility of erroneous conclusions.

General Assumptions

Assumptions are a major source of simulation faults. Law and Kelton [1997] note: “We have never seen a structured walk-through [of the conceptual model] where all of the model assumptions were found to be correct.” Assumptions can address many factors, such as the nature of an algorithm; how other parts of the simulation or federation function; sources and availability of information and data; and the significance of the fidelity of different parts of the simulation. This section should identify the general assumptions pertaining to the part of the conceptual model being described and their implications. Normally such implications constitute a significant part of the simulation’s limitations.

Basic Elements of the Entities and Processes

The basic ingredients of the conceptual model as they relate to simulation elements in the conceptual model are listed in the table below:

Entity and Process Components
Possible states
Tasks/Actions/Behaviors
Relationships/Interactions
Events
Parameters/Factors

These ingredients are not mutually exclusive. It can be helpful to use several orthogonal, complementary views to ensure completeness, such as

- **data view** – shows the flow of data between simulation elements
- **functional view** – describes the hierarchy and static relations between simulation elements
- **behavioral view** -- addresses dynamics such as states, transitions, and interactions associated with simulation elements. This applies to both simulation elements that are entities and simulation elements that are processes represented in the simulation.

The total collection of ingredients should identify the totality of simulation elements in the conceptual model. Identifying dependencies and independence among actions, events, processes, etc. is important. The information included in this section can be used during a conceptual validation review to assess the completeness of the representation’s scope.

Identification of Algorithms

Algorithms define the ways that an entity or process behaves and how it may interact with other things in the simulation. All algorithms should be described and their relationships to entities and processes shown. Sources (pedigrees) of algorithms (and of the data to be used in them) should be specified and the relationship of the algorithm selected to similar algorithms used elsewhere should be noted (if known). Assumptions embedded in algorithms should be noted.

Algorithms should be expressed in standard scientific and technical notation where possible. Although some algorithms can only be expressed easily in the jargon of a particular technical field (such as that employed in decision tables), other algorithms can be appropriately expressed in the more traditional algebraic forms normally employed for calculus, statistics, and differential equations.

Data elements of algorithms should be specified (e.g., the power and antenna gain of a radar representation that uses the standard radar range equation). If precise values of data elements are not available, then the expected data sources should be identified and a postulated value for the data parameter (or a range of possible values) should be given. This kind of algorithmic information is essential if rational judgments are to be made about the potential accuracy and fidelity of the conceptual model.

Simulation Development Plans

This section describes plans for the evolutionary development of the conceptual model over the life cycle of a simulation.

> Example:
>
> The initial version of a sensor representation does not take into account the aspect dependence of target signature strength, although later versions will do so. This section would include plans to develop the simulation element for this enhancement and incorporate it into the conceptual model.

Each development plan should provide as much detail as possible. In addition, each plan should include the time frame during which the enhancement would occur and the implications of its development.

Summary and Synopsis

The summary should clearly identify limitations of the conceptual model as well as summarize its expected capabilities. Any parts of the conceptual model that are incomplete should be identified explicitly and completion dates included. In addition, the conceptual model developer should identify any caveats about the conceptual model that should be known and understood by those performing conceptual validation, by those using the simulation, and by those modifying the simulation for later use.

Conceptual Model Validation

Two factors to consider prior to conceptual model validation are implementation independence and availability of conceptual model documentation.

Implementation Independence

Implementation independence is desired primarily for mission space (representational) aspects of a conceptual model for two main reasons:

- allows evaluation of the conceptual model representation capabilities without consideration of implementation factors
- facilitates reuse of the conceptual model (or its parts) in other applications that may employ a different kind of implementation

Implementation independence is usually not possible for simulation space (control) aspects of the conceptual model, since ideas about how to provide required capabilities are often implementation dependent. In this section, implementation independence of the simulation context, simulation concept, and simulation elements are discussed.

Simulation Context

Typically, information in the simulation context is considered implementation independent when the information is not tied to a particular software paradigm or hardware configuration. However, this is not always the case. In a legacy situation, when a simulation context item is reused, that item may be stated in a manner to maximize compatibility with the previous development and may be expressed in a manner that is implementation dependent (such as using a particular software paradigm). Even in a new simulation development, the scope of the intended application or constraints on resources may force the use of a specific language, software, hardware, or data.

Simulation Concept

A simulation concept is seldom totally implementation independent, particularly if something from a previous simulation development is being reused (e.g., part of a software paradigm, real equipment, or a hardware version). If the simulation concept specifies how something within the simulation will be represented or used with respect to a reused item (e.g., a plan to run the simulation on a certain class of computers or with a particular kind of operating system), the simulation concept becomes implementation dependent.

The HLA FCM is described as “an implementation independent representation, which serves as a vehicle for transforming objectives into functional and behavioral capabilities, and provides a crucial traceability link between the federation objectives and the design implementation” [DMSO, 1999]. “Implementation independent” cannot normally be understood in an absolute or rigorous sense in the FCM, because identification of even one specific federate as the way to satisfy some of the functional and behavioral objectives for a federation involves implementation dependencies.

The bottom line is that one should strive for “reasonable” implementation independence in the simulation conceptual model (as a whole or in part), but one should expect that most parts of a simulation conceptual model will have some level of implementation dependence.

Simulation Element

Implementation independence provides the greatest flexibility in simulation element use. However, the description of a simulation element will not always be implementation independent. Sometimes the simulation element will be described in the software paradigm selected for simulation development. Sometimes the final algorithms of a conceptual model will be simplified approximations of more correct algorithms, selected because only they can be run within the time constraints of the particular simulation implementation. Use of a common descriptive format for all simulation elements within a particular simulation development can facilitate comparison among them to ensure that no unknown inconsistencies or conflicts will interfere with satisfaction of simulation objectives.

Documentation Availability

Descriptions of conceptual models may precede initiation of simulation design, or design may begin prior to the completion of the simulation conceptual model. The earlier descriptions of simulation elements are available, the better, because valuable feedback from conceptual model validation can identify problems and circumvent faults in simulation design and implementation. The importance of this is illustrated by the frequency with which serious problems are found during conceptual model validation reviews.

Validation Overview

Conceptual model validation is assessment or evaluation of the simulation conceptual model (or part of it). Complete conceptual model validation consists of conceptual validation reviews performed on parts of the conceptual model (one of the simulation elements or the simulation context) and the accumulation of these reviews coupled with a conceptual validation review of the simulation concept.

- conceptual model validation review performed on a simulation element determines the fitness of the representation of that item in the simulation
- conceptual model validation review of the simulation concept assesses the overall capability of the simulation
- conceptual model validation reviews of simulation elements and the simulation concept are the only basis for judgment about simulation capabilities for any condition other than those specifically tested

Conceptual model validation is therefore extremely important in simulation assessment, because only a small part of simulation capabilities is tested for any large simulation. A conceptual model validation review may even be performed on the simulation context to ensure that the constraints and boundary conditions imposed upon the simulation concept model are appropriate. [See the special topic Validation for additional information.]

The following comments generally apply to all conceptual model validation reviews.

Validation Methods

Conceptual model validation is normally based on SME review. Quantitative assessments such as sensitivity analyses and comparison with data from various sources may be employed in the review, as well as SME expert opinion. [For additional information see the special topics on SMEs and V&V techniques.]

Review Scope and Criteria

Conceptual model validation reviews ensure simulation correctness and enhance simulation credibility most when the scope of the review and criteria that will be used in the assessment are stated explicitly. Review scope and evaluation criteria should be defined before conceptual model validation reviews commence. The review process works most smoothly when the review scope and evaluation criteria are agreed to by the User and the Developer as well as by reviewers. Conceptual model validation evaluations should always be performed within the context of expected simulation application.

Review Format

All reviews related to a particular simulation should use similar reporting formats, and where possible they should use reporting formats that are compatible with reviews of other simulations applied to the same kind of application. Reports of evaluation reviews should include information and rationale as well as conclusions.

Review Scheduling

The scheduling of conceptual model validation reviews depends upon several factors. First, a description of the simulation conceptual model must exist. In the past, some simulation developments did not require distinct and complete documentation of the simulation conceptual model. This severely hampered conceptual model validation reviews, allowing simulation problems that could have been discovered early in development to remain undiscovered until they manifested themselves in simulation use. This can be very costly. A majority of software faults derive from faulty requirements [Lewis, 1992]. It can cost as much as 100 times more to correct a software fault late rather than early [Miller, et al, 1993].

Depending upon the simulation development paradigm used, a “final” and full simulation conceptual model may be available prior to high level or detailed design. However, sometimes the final (full) conceptual model description may not be available until after design and implementation have begun. Preliminary conceptual model validation reviews can be performed on a partial and preliminary conceptual model. While this kind of conceptual model validation review can help to detect ideas that will cause simulation faults, conceptual model validation of a preliminary conceptual model should never be used as a basis for evaluation or assessment of the simulation, because only the final conceptual model can be the basis for that judgment. When validation review resources are limited, discretion must be employed in their use to ensure both that a sound basis exists for judgment about simulation suitability (i.e., conceptual model validation of the final conceptual model) and also that the simulation development benefits from as much early conceptual model review as resources allow.

A second factor affecting the scheduling of conceptual validation reviews is availability of appropriate reviewers. Often an appropriate administrative structure through which conceptual validation review personnel, especially SMEs who are outside the simulation development team, can be engaged does not exist until well along in simulation development. Typically this lack of appropriate administrative structure prevents timely verification and validation review of simulation requirements. As a consequence, the simulation development contract may be issued on the basis of faulty requirements, which can have major cost implications for simulation development. Lack of early V&V input can have similar results.

> Example:
>
> The simulation development contract may fail to require that distinct documentation of the simulation conceptual model be provided in a timely fashion, and instead leave the simulation conceptual model to be deduced from simulation design documentation such as the software development document (SDD) and the detailed software detailed requirements document (SDRD). This can be an even more significant problem if the SDD or SDRD is not done well or does not consistently identify assumptions and sources, etc., associated with items in the document.

Resource limitations for conceptual validation reviews may restrict the reviews to only final versions of conceptual models, and in many cases, will restrict the reviews so that only the more critical parts of the simulation are reviewed. Because of this, it is very important that experienced VV&A personnel be sought to provide advice about how to accomplish as much as possible of the required conceptual validation within the available resources. This is the normal situation: One cannot do as much V&V as desired or, in some cases, as required to reduce the risk that a simulation will not be fully able to satisfy its requirements.

Validation Process

Conceptual model validation reviews have two purposes:

- increase simulation correctness
- enhance simulation credibility

To enhance simulation credibility normally requires that conceptual model validation reviews be performed (at least in part) by those outside the simulation development team, and may require that the conceptual model validation review team include all with vested interests in the simulation.

Establish Review Scope and Assessment Criteria

Ideally the scope would include everything, but in practice the scope of conceptual model validation is often restricted to the more significant aspects of the simulation. Assessment criteria come in two flavors. The first concerns the capability of the conceptual model to satisfy the requirements specified for the simulation in general; this is part of the general V&V of the simulation. The second concerns the capability of the conceptual model to support a particular application of the simulation and is oriented toward support of an accreditation decision. This may require conceptual validation review for each particular application, as shown in the example below.

> Example:
>
> A simulation may be intended to have the capability of representing many different kinds of weapon systems, but a particular application of the simulation is only going to address a limited set of weapon types.
>
> – The first set of assessment criteria would cover all weapon types that the simulation is to be capable of representing. However, such assessments normally would not address the full range of employment possibilities for every weapon.
>
> – The second set of assessment criteria would only cover the weapon types of the intended application and would address the full range of employment possibilities for the specified weapon types needed for that application.
>
> It may be necessary to perform a conceptual validation review for each particular application, especially if an application introduces stringent demands or unusual circumstances. If a missile defense simulation needs to evaluate new guidance approaches for the interceptor, a new conceptual validation may be necessary to determine that algorithms in the conceptual model can adequately support those approaches to interceptor guidance. Material from previous conceptual validations can reduce the effort required to perform additional conceptual validations.

The review scope and assessment criteria must be established authoritatively. The User must issue the document that establishes the conceptual model validation review scope and assessment criteria. Otherwise, the simulation development may not be responsive to findings of the review. Normally the contents of this document are drafted by an element of the V&V or IV&V team for the simulation and incorporate Developer perspectives appropriately.

Identify and Orient Review Personnel

The subject matter determines the technical expertise required. Vested interests (e.g., interests of a program office whose system is to be represented in the simulation) also influence who should be included on the conceptual model validation review team. An ideal situation would have a review team that both represented all parties with vested interests and also contained other qualified experts (who have no vested interest) for objectivity. Some simulation developments use a formal SME nomination/application form (somewhat similar to a resume) to capture relevant information about prospective conceptual model validation SMEs in a structured and common format. This helps to limit criticism about SME appropriateness when the reviews uncover problems. Normally SMEs need orientation about the simulation, its intended applications, the criteria for the review and assessment, and, in some cases, the descriptive format for the conceptual model (as when a design accommodation method for describing the conceptual model is employed). [See the special topic Subject Matter Experts and VV&A for additional information.]

Develop Review Process

This involves determining how the review will be conducted (e.g., via documents only; from documents supplemented by some interaction with the simulation development team; mainly by interactive dialogue between the reviewer and the simulation development team; by experiments with legacy code to help deduce its underlying conceptual model; etc.) and how the review will be reported. A structured review report form helps to ensure consistency, comprehensiveness, and comparability for reviews of different parts of a simulation when a variety of review personnel are used. The conceptual model validation review process also includes how the conceptual model description is collected and passed to review personnel and how meetings to support the review process are arranged and reports and other documents managed, etc.

Conduct Reviews

This involves scheduling review personnel (i.e., members of the simulation development team supporting the conceptual model validation reviews as well as SMEs and others from outside the simulation development team), getting appropriate materials (e.g., conceptual model descriptions, review orientation and report forms) to those involved, monitoring review processes, collecting reports from the reviews, etc. Conceptual model validation of a major simulation may require reviews of all the major systems represented by the simulation as well as reviews of the overall simulation. Sometimes multiple reviews are conducted so all vested interests can be accommodated. Including adequate resources in the V&V planning for both administration and performance of these reviews is essential. It is wise to begin with reviews of the more critical parts of the conceptual model so that adequate time and attention will be given to the more important aspects of the conceptual model validation review.

Submit Review Results for Response

The Developer may have a different perspective than that from the initial review. It is wise to provide opportunity for the Developer to respond to the review. Sometimes a misunderstanding reported by the review has to be corrected. Sometimes a fault is identified and the Developer devises (and implements) a way to correct it. The purpose of this kind of iteration between the reviewers and the Developer is to eliminate unnecessary differences about the reviews and to make sure that final versions of the reviews reflect the most recent situation (such as the faults corrected).

Synopsize Reviews and Draw Conclusions

Multiple reviews of the same simulation element are consolidated and conclusions drawn.

> Example:
>
> The simulation representation of a radar may be reviewed by SMEs from the program office developing the radar and by other SMEs from different agencies, organizations, and academic institutions. The overall conclusions from all the reviews are integrated in a coherent fashion and included in the accreditation assessment report.

Typically this synthesis is performed by the leader of the conceptual model validation effort for the simulation.

Conceptual Model Validation Review Reports

The types of information that should be included in a conceptual model validation review report are listed in the table below:

Validation Review for Conceptual Model Report Checklist	
✓	Identification of the conceptual model (or the part of it) being reviewed by name, version, date, etc. of the conceptual model when such exist
✓	Review personnel (names, contact information, areas of expertise, etc.)
✓	Information used during review: documents, interactions with development team members by name and date, etc.
✓	Scope and criteria for representational assessment employed in the review

✓	Representational enumeration (explicitly):
--	• Are all elements and aspects of the item (entities, states, behaviors, actions, tasks, etc.) to be represented included?
--	• Which ones were omitted?
--	• Are those omitted pertinent for intended simulation applications?
✓	Assessment of assumptions pertaining to conceptual model or the part being reviewed.
--	• Are all assumptions identified?
--	• Are implications of these assumptions clearly and correctly identified?
--	• What assumptions were omitted and what implications need clarification?
✓	Assessment of algorithms used.
--	• Do the algorithms provide adequate fidelity (as expressed in terms of accuracy, resolution, etc.) for the simulation to support the intended applications, to satisfy simulation requirements, and to comply with criteria given as guidance for the conceptual model validation review?
--	• Are the algorithms correct and appropriate, with acceptable and authoritative pedigrees?
--	• What is the relation of these algorithms to "standard" algorithms used elsewhere within the Defense community?
✓	Conclusion and synopsis of the review findings, clearly separating fact from interpretation and explaining the significance of the findings
✓	Recommendations for improving simulation correctness or credibility or future conceptual model validation review processes

Costs and Limits on Conceptual Model Validation

Resources required to perform conceptual model validation depend upon the size and complexity of the simulation being reviewed, the quality and correctness of the conceptual model documentation, and the level of validation required. Experience has shown that there are three basic levels of simulation validity (i.e., the level of credibility warranted by the simulation applications):

- inspection level
- review level
- demonstration level

It should be noted that there are no widely accepted terms for these levels of credibility and there are obvious other connotations attached to these terms when they occur in other contexts.

Inspection Level Validation/Credibility - cannot go beyond face validation for a number of reasons. Data about the subject may be lacking; resources for more thorough VV&A may not be available; or the expected application of the simulation may not justify more extensive VV&A. Whatever the cause, inspection level validation results in a statement of expert opinion that declares the simulation responses to be as expected.

- Theater-level and campaign-level military simulations, as well as simulations of national economic and political behavior, generally fall into this validation category. While parts of these models can be validated more robustly, the composite models can only be validated at the inspection level.
- The entire class of what some call "unvalidatable" simulations (i.e., simulations for which reliable real world data do not exist for detailed comparison [Hodges and Dewar, 1992]) is also limited to this level of validation. Lack of data about the subject represented for this kind of simulation restricts it to inspection level validation/credibility regardless of how many resources are applied to VV&A.

Review Level Validation/Credibility -- establishes that the simulation has structural validity and acceptable predictive validity for test cases considered. It often also establishes that simulation behavior is sufficiently well behaved from replication to replication that it has mathematical stability and replicative validity [Zeigler 1998]. Both adequate data about the subject being modeled and adequate resources for extensive VV&A have been available to support this level of validation.

Demonstration Level Validation/Credibility - is reserved for simulations that must work correctly all the time. These are simulations involved in safety-critical systems, such as simulations supporting medical diagnostic software and nuclear power plant control or aircraft flight control systems. Their performance and response can be predicted consistently and correctly according to objective criteria so that adequate confidence can be placed in them for the critical functions they serve.

The higher the validation/credibility level, the greater the cost for conceptual model validation. Documentation of simulation elements can take scores of pages (and sometimes much more). It is not uncommon for conceptual model validation reviews to require face-to-face meetings between review personnel and simulation development personnel. This suggests that conceptual model validation reviews of even relatively simple simulation elements such as a radar or missile representation can require weeks or months of effort for a major simulation. The more complete and understandable the conceptual model documentation, the easier it will be for conceptual model validation review personnel to understand and correctly assess the conceptual model, which reduces the resources required for conceptual model validation reviews.

The more complex the subject represented by the simulation, the higher will be the cost to achieve a specified level of validity/credibility. The level of validity attributed to a simulation is limited by the level of knowledge about the real-world aspects to be represented. Logical consistency and completeness of a simulation conceptual model may be established, but without real-world confirming data, it will not be possible to claim more than theoretical validity/credibility (inspection level validation) for the simulation.

Additional discussion of validation costs may be found in the special topic V&V Cost.

Simulation Space and Mission Space

The conceptual model for a simulation has to address both simulation space (i.e., the simulation operational and functional capability) and mission space (i.e., the representational capability of the simulation). Comments thus far about conceptual model validation have focused on representational issues of mission space. However, conceptual model validation reviews also should address simulation space issues.

> Example:
>
> New Defense simulations are required to be HLA compatible [USD(A&T)[2], 1996]. A conceptual model validation review would comment on this aspect of the simulation. Such comments in a conceptual validation review about HLA compliance would indicate which version of the Real Time Infrastructure (RTI) was being assumed, what HLA compliance testing/demonstration was planned, which other simulations (HLA federates) were expected to interact with the simulation, etc.

Other simulation space considerations might have to do with data collection capabilities for analysis of simulation results, for allowing user/operator observation and manipulation of the simulation while it is running, for capability of the simulation to interact with real systems or other specific simulations not included in the HLA compatibility requirement, etc. Simulation space considerations that must be addressed in conceptual model validation reviews are those covered by simulation requirements and criteria specified for the conceptual model validation review.

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RPG References in this Document

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